

IN THE SPECIFICATION

On page 1, lines 1-2, delete the title A MAGNETIC TUNNEL JUNCTION SENSOR WITH NON-SHUNTING STABILIZATION and substitute therefore A MAGNETIC TUNNEL JUNCTION SENSOR HAVING A FREE LAYER BIASED BY ELECTRICALLY INSULATING HARD BIAS LAYERS.

Pages 5-6, amend the paragraphs beginning at line 1, page 5 and ending at line 7 on page 6.

Fig. 1A shows an illustrative embodiment of a magnetic tunnel junction (MTJ) sensor 10 from the prior art. Sensor 10 is viewed from the air bearing surface (ABS) so that, in operation, the magnetic medium (not shown) moves in the image plane vertically with respect to MTJ sensor 10. MTJ sensor 10 includes an MTJ stack 12 disposed between a first shield (S1) layer 14 and a second shield (S2) layer 16. MTJ stack 12 may be characterized as an upper electrode 18 separated from a lower electrode 20 by a tunnel barrier 22. Upper electrode 18 includes a ferromagnetic (FM) pinned layer (PL) 24 having a magnetic moment that is pinned by an exchange-coupled antiferromagnetic (AFM) layer (AF) 26, and a second lead (L2) layer [[28]]. The lower electrode 20 includes a FM free layer 30 and a first lead (L1) layer 32. MTJ stack 12 operates in the usual manner known in the art except that the stabilization biasing of free layer (FL) 30 is provided by a hard magnetic (HM) layer 34 disposed on each side of MTJ stack 12. To prevent a loss of sensitivity from undesired sense current shunting, HM layers 34 are sandwiched between two insulating layers 36 and 38 substantially as shown. Practitioners in the art can readily appreciate that the several layers outside of MTJ stack 12 should be precisely created in a series of steps following an initial etching procedure. The usual processes known in the art give rise to misalignment between the

narrow ends of the various layers at the edges of MTJ stack 12, leading to unit performance variations and high unit rejection rates.

Fig. 1B shows an air bearing surface (ABS) view of another illustrative embodiment of a MTJ sensor 40 from the prior art. MTJ sensor 40 can be considered to include the end regions 42 and 44 separated from each other by a central region 46. The active region of MTJ sensor 40 is the MTJ stack 48 formed in the central region 46. MTJ stack 48 has a generally rectangular shape with a front face (shown) at the ABS, a back edge (not shown) opposite to the front edge and two opposite side edges 50 and 52. MTJ stack 40 includes a first electrode 54 and a second electrode 56 between which is disposed a tunnel barrier layer 58. First electrode 54 includes a pinned layer 60, an AFM layer 62 and a seed layer 64, where pinned layer 60 is disposed between tunnel barrier layer 58 and AFM layer 62, which is disposed between pinned layer 60 and seed layer 64. Second electrode 56 includes a free layer 66 and a cap layer 68, where free layer 66 is disposed between tunnel barrier layer 58 and cap layer 68. AFM layer 62 is exchange coupled to pinned layer 60 providing an exchange field to pin the magnetization direction of pinned layer 60 perpendicular to the ABS. The magnetization of free layer 66 is oriented parallel to the ABS (absent other external magnetic fields) and is free to rotate in the presence of a signal magnetic field. As with MTJ sensor 10 (Fig. 1A), free layer stabilization bias is provided by the [[HB]] (H.B.) layers 70, which are sandwiched between the insulation layers (I2) 72 and 74 to prevent sensitivity losses through shunting of MTJ stack 48.

Pages 10-11, amend the paragraph beginning on page 10, line 22 and ending on page 11, line 10.

Figs. 2A and 2B show schematic representations of the air bearing surface (ABS) of exemplary embodiments of the MTJ sensor of this invention wherein the free layer stabilization is provided by non-conducting antiferromagnetic layers made of material such as nickel oxide or certain phases of iron oxide. The MTJ sensor 76 (Fig.

2A) includes a central active region 78 disposed between two side regions 80 and 82. A first lead (L1) layer 84 is a substrate on which the FM free layer 86 is first deposited, followed by the tunnel barrier layer 88, the FM pinned layer (PL) 90 and the first AFM layer 92, which is exchange-coupled to FM pinned layer 90 for the purposes of pinning the magnetic moment of FM pinned layer 90 to the desired direction. The layer stack thus produced is then etched to remove all materials in the end regions 80 and 82 down to FM free layer (FL) 86, a portion of which is left in the side regions 80 and 82 substantially as shown. After the etching step, which defines active region 78 of MTJ sensor 76, the second AFM layer 94 is deposited in direct contact with the portions of free layer 86 remaining in side regions 80 and 82. The material used for AFM layer 94 should be electrically insulating (such as nickel oxide or certain phases of iron oxide). If first AFM layer 92 should be oriented magnetically orthogonally to the magnetic moment second AFM layer 94, the materials should be selected so that the blocking temperatures of AFM layers 92 and 94 differ sufficiently to permit the AFM layer 94 to be magnetically set without disturbing the earlier magnetic settings of first AFM layer 92.

Pages 11-14, amend the paragraphs which begin at line 19 on page 11 and end at line 16 on page 14.

In contrast with the "top" embodiment of MTJ sensor 76 (Fig. 2A), Fig. 2B shows a representative embodiment of a "bottom" MTJ sensor 98, which is analogous to the "top" MTJ sensor 76. MTJ sensor 98 includes the active region 100 and the side regions 102 and 104. The first lead (L1) layer 106 is used as a substrate for depositing a first AFM layer 108, a FM pinned layer (PL) 110, a tunnel barrier layer 112 and a FM free layer (FL) 114. At this point during the fabrication procedure, all material is etched from the side regions 102 and 104 down to first lead (L1) layer 106 so that no trace of first AFM layer 108 remains. The second AFM layer 116 is then deposited up to the existing level of free layer 114. Additional ferromagnetic material is deposited over

both active region 100 and side regions 102 and 104 to complete FM free layer 114 substantially as shown in Fig. 2B. Finally, a second lead (L2) layer 118 is deposited to complete MTJ sensor stack 98. As before, the material used for second AFM layer 116 should be non-conducting to avoid undesired shunting losses to MTJ sensor sensitivity. Also, as discussed above in connection with Fig. 2A, the materials selected for first and second AFM layers 108 and 116 should be chosen to permit the processing of AFM layer 116 without exceeding the blocking temperature of the pre-existing AFM layer 108.

The sensor of this invention may also be embodied using conducting materials for stabilizing the free layer, as is now described. Figs. 3A and 3B show schematic representations of the ABS of exemplary MTJ sensor embodiments of this invention wherein the free layer stabilization is provided by conductive hard magnetic (HM) layers separated from the MTJ stack active region by thick insulation layers. In Fig. 3A, the MTJ sensor 120 is shown with the active region 122 separating the two end regions 124 and 126. This is a "top" MTJ sensor configuration. The first lead (L1) layer 128 is deposited followed by the FM free layer (FL) 130, the tunnel barrier layer 132, the FM pinned layer (PL) 134 and the first AFM layer 136. At this point, all layer materials outside the active region 122 are etched down to but not completely through FM free layer 130. Using masking and liftoff techniques known in the art, a hard magnetic (HM) layer 138 is deposited only within the outer portions of end regions 124 and 126, respectively. A non-conducting insulating layer (II) 140 is deposited to fill the remaining empty portions of end regions 124 up to the level of first AFM layer 136. Finally, a second lead (L2) layer 142 is deposited to complete the device. MTJ sensor 120 permits excellent free layer stabilization because of the direct contact of a substantial portion of HM layer 138 with FM free layer 130 in end regions 124 and 126 without contact with any part of active region 122, thereby avoiding any loss of sensitivity from undesired shunting of sense current.

Fig. 3B illustrates the "bottom" MTJ sensor 144 equivalent to the "top" MTJ sensor 120 (Fig. 3A). MTJ sensor 144 includes the active region 146 separating the two

end regions 148 and 150. Beginning with the first lead (L1) layer 152, the MTJ stack is built beginning with the first AFM layer 154 followed by the FM pinned layer (PL) 156, the tunnel barrier layer 158, and the FM free layer 160. These material layers are then etched in end regions 148 and 150 down to expose first lead (L1) layer 152 and the insulating layer (I1) 162 is then deposited to fill end regions 148 and 150 up to the top of free layer 160, after which additional ferromagnetic material is added to build up free layer (FL) 160 over active region 146 and end regions 148 and 150, substantially as shown. Thereafter, using a combination of masking and liftoff techniques known in the art, the HM layer 164 is deposited in the outer portions of end regions 148 and 150 in direct contact with free layer 160 and, finally, the second lead (L2) layer 165 is deposited to complete MTJ sensor 144.

Figs. 4A and 4B show schematic representations of the ABS of exemplary MTJ sensor embodiments of this invention wherein the free layer stabilization is provided using conductive AFM layers separated from the MTJ stack by thick insulation layers, similarly conceptually to the discussion above in connection with Figs. 3A and 3B. In Fig. 4A, the top MTJ sensor 166 includes the active region 168 disposed between the two side regions 170 and 172. Operation and fabrication of MTJ sensor 166 in Fig. 4A may be appreciated with reference to the above discussion of Fig. 3A wherein the layers, including FL, PL, I1, L1 and L2, are the same except that, instead of HM layer 138 (Fig. 3A), MTJ sensor 166 uses the conductive AFM layers 173 to provide stabilization of the FM free layer 174. By permitting conductive as well as non-conductive materials to be considered for second AFM layer [[172]] 173, a wider range of choices is made available for resolving material conflicts between second AFM layer [[172]] 173 and the first AFM layer 176.

Fig. 4B shows the "bottom" MTJ sensor 178 having the active region 180 disposed between the two end regions 182 and 184. Fabrication and operation of MTJ sensor 178 in Fig. 4B may be understood with reference to the above discussion of Figs. 3A and 4A [[.]] wherein the layers, including FL, PL, I1, L1 and L2, are the same. In Fig. 4B, the second AFM layer 186 is disposed directly in contact with the FM free layer

188 in the outer portions of end regions 182 and 184. Again, permitting a wider range of materials to be used for longitudinal stabilization of free layer 188 may resolve otherwise difficult material conflicts.

Fig. 7 shows a schematic representation of the ABS of an exemplary MTJ sensor embodiment of this invention wherein the free-layer stabilization is provided by non-conducting HM layers abutting the free layer and MTJ stack. The MTJ sensor 226 includes the active region 228 disposed between the two side regions 230 and 232. Fabrication and operation of MTJ sensor 226 may be understood with reference to the above discussion of Figs. 2A and 2B except that the etching step is conducted completely through the FM free layer (FL) 234 into the first lead (L1) layer 236 so that FM free layer 234 is truncated at the edge of the active region and does not extend into side regions 230-232. The tunnel barrier layer 238, the FM pinned layer (PL) 240, the AFM pinning layer 242 and the first portion of the second lead (L2) layer 244 are also truncated at the edge of active region 228 by the same etch process. A nonconductive HM layer 246 is then deposited in side regions 230-232 using any useful masking and lift-off procedure so that HM layer 246 material fills side regions 230 and 232 and abuts the edges of the MTJ stack layers 234, 238, 240 and 242 to provide stabilization of FM free layer 234 substantially as shown. Finally, the etching mask is removed and the remainder of second lead (L2) layer 244 is deposited to complete MTJ sensor 226. Because HM layer 246 is nonconductive (for example, a nickel-oxide or barium ferrite compound), there is no shunting of sense current flow in active region 228 (the MTJ stack). No thin insulator layers are needed and only one lift-off step is required. Because MTJ sensor 226 is symmetric except for active region 228, it may be readily appreciated that this discussion in connection with Fig. 7 applies to either a "top" or "bottom" MTJ sensor configuration.

Pages 16-17, amend the paragraph beginning on page 16, line 21 and ending on page 17, line 4.

Fig. 8 shows a flow chart illustrating an exemplary method of this invention for fabricating the exemplary MTJ sensor 76 (Fig. 2A) of this invention. In the step 248, a first lead (L1) layer formed and serves as a substrate on which the FM free layer is deposited in step 250, followed by the conducting tunnel barrier (TB) layer in the step 252, the FM pinned layer in the step 254 and the first AFM layer in the step 256. Finally, a photoresist layer is added in the step 258 and treated to remove the resist over everything except the active region in the step 260. The layer stack thus produced is then etched in the step 262 to remove all materials in the end regions down to (but not completely through) the FM free layer, a portion of which remains in the side regions. After etching step 262, which defines the MTJ stack, the longitudinal biasing layer is deposited in the step 264 directly over the free layer portions exposed in the side regions. After the remaining photoresist is washed away (together with the unwanted longitudinal bias layer material in the active region) in the step 266, a second lead (L2) layer is deposited in the step 268 to complete the MTJ sensor.

On page 27, lines 1-2, delete the title A MAGNETIC TUNNEL JUNCTION SENSOR WITH NON-SHUNTING STABILIZATION and substitute therefore A MAGNETIC TUNNEL JUNCTION SENSOR HAVING A FREE LAYER BIASED BY ELECTRICALLY INSULATING HARD BIAS LAYERS.